A STUDY ON EFFECTIVE THERMAL CONDUCTIVITY AND DIELECTRIC PROPERTIES OF PARTICLE FILLED EPOXY COMPOSITES

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

In

(Mechanical Engineering)

By

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Department of Mechanical Engineering

NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA

MAY, 2012

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Rourkela

CERTIFICATE

This is to certify that the work in this thesis entitled ***"A Study On Effective Thermal Conductivity And Dielectric Properties Of Particle Filled Epoxy Composites"*** by ***Abhijit Halder***, **has** been carried out under my supervision in partial fulfilment of the requirements for the degree of ***Bachelor of Technology*** in ***Mechanical Engineering*** during session 2011 - 2012 in the Department of Mechanical Engineering, National Institute of Technology, Rourkela.

To the best of my knowledge, this work has not been submitted to any other University/Institute for the award of any degree or diploma.

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DATE: 10th May, 2012

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Abstract

Low dielectric along with thermally conductive fillers is required for high heat output devices for electronic packaging or printed circuit board (PCB) substrate materials. Hardened neat epoxy in lieu of having good mechanical strength cannot satisfy this demand owing to very low thermal conductivity. In view of this, in the present research the dielectric as well as thermal characteristics of a new category of hybrid composite has been studied.

The present research consists of three parts: The first delineating the details of a series of epoxy resin based composite reinforced with solid glass microsphere (SGM) separately, as well as solid glass microsphere (SGM) with boron nitride (BN) ranging to different volume fraction has been fabricated using hand-lay-up technique. Second evaluate the effective thermal conductivity (k_{eff}) using finite element method (FEM), also using various other numerical thermal conductivity models available from literature survey. The last part examines the dielectric characteristic of this hybrid composite, dielectric constant measurements are done by using a HIOKI- 3532-50 Hi-Tester Elsier Analyser with an applied AC voltage of 500mv in the frequency range of 1 kHz to 1000 kHz. This study excogitates that while incorporation of SGM subdues the dielectric constant of the composite, addition of BN ameliorates the thermal conductivity.

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Chapter 1
Introduction

Chapter 1

INTRODUCTION

Composite Materials

Composite materials (abbreviated as composites) are naturally obtained or engineered fusing two or more constituent materials with significantly different chemical and physical properties which remain secerned and distinct at macroscopic or microscopic level within the finished structure. The constituent material is basically of two categories: matrix and reinforcement, the matrix supports the reinforcement providing support against mechanical and environmental damage by surrounding and maintaining their relative position, while the reinforcement bestow special mechanical and physical properties such as strength, dielectric, stiffness etc. Hence, a material property that is unavailable in individual constituent is obtained by their synergism. The aim is to obtain the superior property minimising the adverse effects.

Traditional materials have been presently substituted by composite materials due to their low density, high strength application, toughness and high creep resistance, high tensile strength at elevated temperature, high strength-to-weight ratio etc. Composites are generally anisotropic materials; where the matrix is usually material with high toughness or ductility and reinforcements are of low density with high strength and stiffness, and their union produces desirable property depending on their design, orientation, volume fraction and other physical properties of constituent materials. In composites, materials are commingled in such a way as to enable us to better virtuousness while deprecating to some extent the effects of their deficiencies. This process of optimisation can unloosen a designer from the constraints associated with the selection and manufacture of conventional materials. He can make use of sturdier and lighter materials, with properties that can suit particular design requirements. Due to the ease of manufacturing intricate shapes using composites, the consideration of an established design in terms of composites can often lead to both cheaper and ameliorated solutions. The 'composites' concept is not human invented. Natural composite material for example wood consisting of one species of polymer cellulose fibres with better strength and stiffness — in a resin matrix of another polymer, the polysaccharide lignin. Nature does a much better job of designing and manufacturing than we do, although man recognized the way of overcoming two major disadvantages of natural wood — that of size (limited transverse dimension of tree), and of anisotropy (different marked property in the axial and radial directions) — was to make the composite material that we designate as plywood. Bone, teeth and mollusc shells are other natural composites.

Types of Composite Material

Composites are broadly classified in accordance with the matrix material. They are:

- Metal Matrix Composites (MMC)
- Ceramic Matrix Composites (CMC)
- Polymer Matrix Composites (PMC)

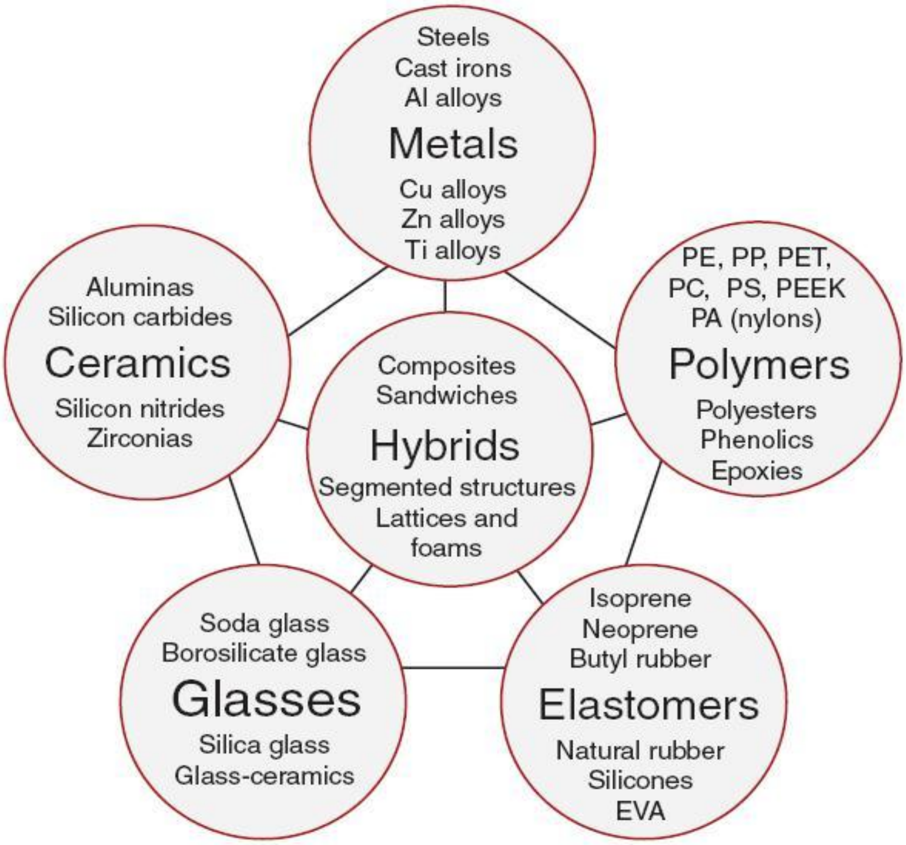

Fig 1.1: Conventional classification of composite materials in accordance to matrix material

Metal Matrix Composites

These are composites with matrix constituent being metal, while the other can be another metal or a ceramic or organic compound. Metal Matrix Composites are superior to monolithic metals due to their high specific strength, can operate in wide range of temperatures, better electrical and thermal conductivity, higher specific modulus, low co-efficient of thermal expansion and do not display outgassing. Due to these attributes, metal matrix composites are considered for various applications viz. carbide drills, tank armours, modern high-performance sports car, radio frequency quadrupoles (RFQs) etc. A typical example is the titanium carbide cermet which constituting 30% nickel matrix reinforced with 70% TiC particles demonstrates high specific strength and stiffness at higher temperatures.

Ceramic Matrix Composites

These are composites blending ceramic reinforcements in ceramic matrix forming ceramic fibre reinforced ceramic (CFRC's). The main objective is to obtain high fracture toughness and crack resistance. Naturally it is found that there is an ensuant melioration in strength and stiffness of ceramic matrix composites. The ceramic matrices are usually glass, glass ceramics (lithium aluminosilicate), carbides (SiC), nitrides (SiN_4, BN), oxides (Al_2O_3, Zr_2O_3, Cr_2O_3, Y_2O_3, CaO, ThO_2) and borides (ZrB_2, TiB_2). The reinforcements which are normally high temperature inorganic materials including ceramics may be in the form of particles, flakes, whiskers and fibres. The commonly used fibres are carbon, silicon carbide, silica and alumina. Most significant class of ceramic matrix composites are Carbon-carbon composites that can resist temperatures as high as 3000^0C. These consist of carbon reinforced fibres dispensed in a carbon matrix.

Polymer Matrix Composites

Commercial production of composites often using resin solutions are known as polymer matrix composites. Polymers are co-valently bonded macromolecular repetitive structural unit, hence, their mechanical property is inadequate for various structural purposes. Particularly their strength and stiffness is low compared to metals and ceramics. However, this defiance is overcome by reinforcement of other constituent materials like ceramics or organic compounds. Low pressure and temperature requirement whether the polymer is a thermoset (processing temperature 200°C)or a thermoplastic (processing temperature 300°C to 400°C) [28] along with simpler manufacturing equipment for fabrication of these composites concatenate to its suitability in real-life applications.

Panoptic view of polymers and Composite Polymers

Conventional (thermosets) rubber /elastomers

Three-dimensional elastic network covalently cross-linked with 'junction'. During exhaustive heating the junction may survive till the thermo-oxidative degradation temperature reached.

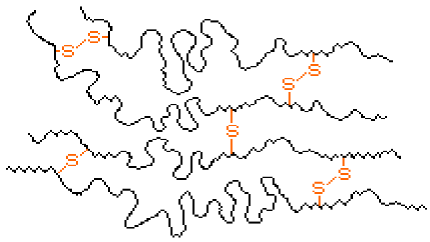

Fig 1.2: The cross-linked chain of natural rubber with sulphur linkage

Thermoplastic Elastomers

These are a class of physical cross-links within a three-dimensional elastic network, such as glassy amorphous or crystalline domain in soft amorphous matrix.

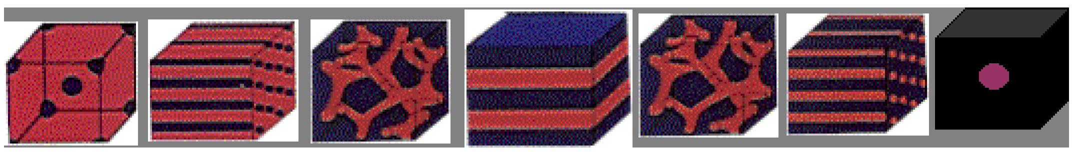

Fig1.3: Evaluation of thermodynamic equilibrium morphology of a typical AB-diblock polymer

Bio-based Polymers

Bio-polymers are procured from renewable resources like plants and/or bacteria such as polyhydroxyalkanoates and cellulose. This also includes polymers obtained from laboratory modification of biopolymers or polymerising bio-based monomers.

Fig 1.4: Bio-based source polymers cotton, soybeans and a culture of Wautersia *eutropha bacteria*

Foams

These are flexible or rigid, cross-linked or thermoplastics, either physically or chemically foamed.

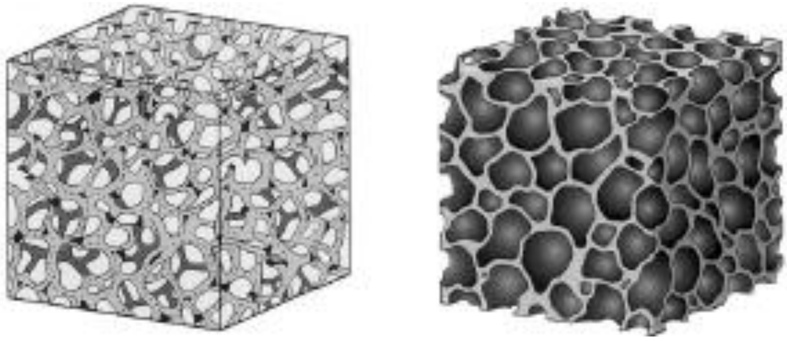

Fig 1.5: Illustration of slab of open-cell foam and closed-cell foam

Liquid Crystalline Polymers

The molecular arrangement manifests both orientation order and translational order in a crystalline arrangement. In liquid crystal arrangement orientations are ascertained in the preferred direction.

Fig 1.6: Polymer demonstrating liquid crystalline order in various polyaromatic heterocycles

Polymer Matrix Composite can be further dissevered into three groups on the basis of reinforcement material used. They are:

- Fibre Reinforced Polymer (FRP)
- Particle Reinforced Polymer (PRP)
- Hybrid Composites/Structural Composites

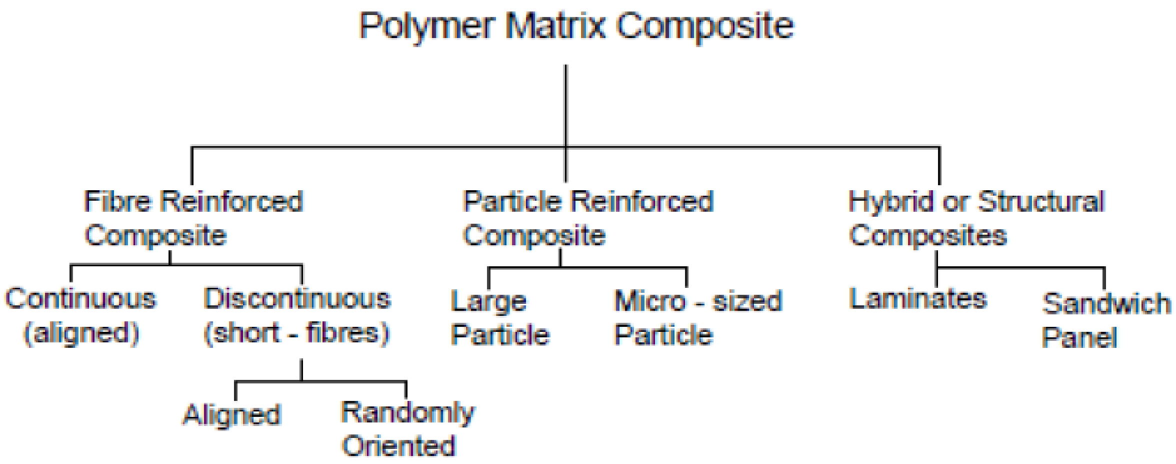

Fig 1.7: Hierarchical representation of Polymer Matrix Composite

Fibre Reinforced Composite

A composite comprises of three components (i) Fibre in discontinuous or dispersed phase (ii) Matrix as continuous phase, (iii) the fine region known as interface. These are high-performance fibre composite obtained by fibre molecules of cross-linked cellulose with resins in FRC matrix material through proprietary molecular re-engineering process, which yields a product of exceptional mechanical properties.

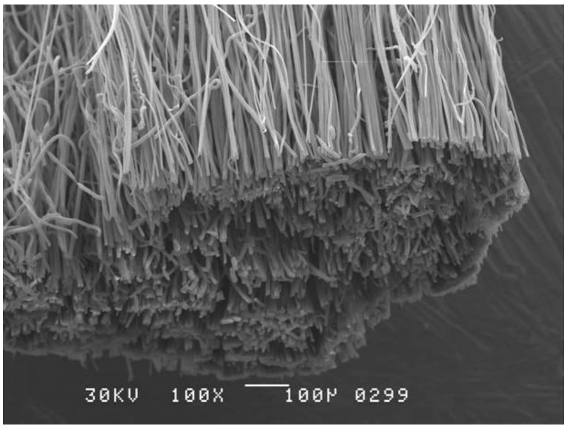

Fig 1.8: Cross-sectional view of high strength fibre tow

Particle Reinforced Composite

These are composites fabricated using particle as constituent material. Particles can be metals, ceramics, amorphous material and other organic compound so as to obtain a desired property unavailable in neat polymer matrix material. Particles are used generally to increase modulus, deduce ductility, reduction of weight due to its low density as well as to reduce the overall cost. Some of the crucial properties are low density, high melting point, corrosion resistivity, high strength and stiffness, wear resistant etc. Some ceramic filler particles also possess good electrical and thermal insulation properties; some are piezoelectric materials, while some behave as superconductors at very low temperatures. Several polymeric particles of materials like talc, clay, mica, calcium carbonate, titanium oxide, wood dust, sand, silica, alumina, asbestos, glass beads, metal flakes, carbon powder, ceramic grains etc. are generally used. Besides beefing up the composite, particles also suffice other purposes. They act as additives to modify the creep, impact, hygral, thermal, electrical and magnetic properties as well as wear resistance, inflammability and other such properties of the composite.

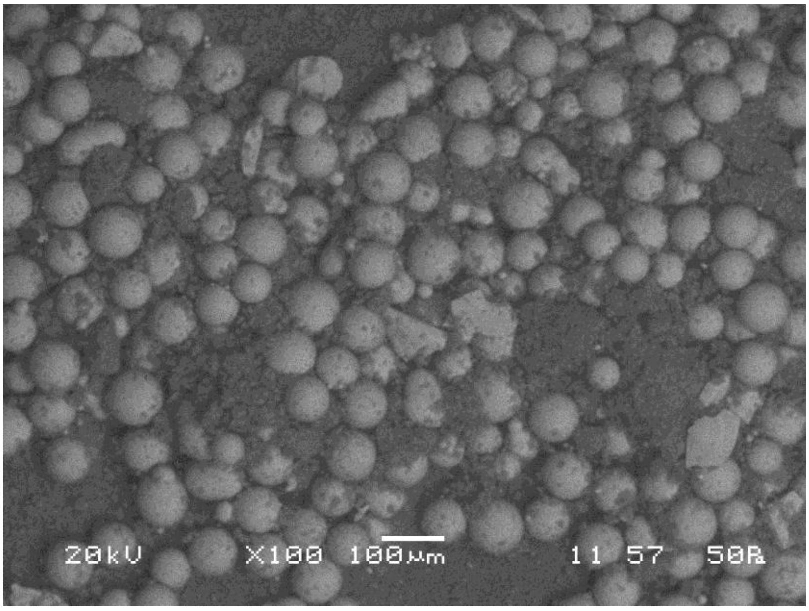

Fig 1.9: SEM micrograph of epoxy resin filled with boron nitride (BN) and solid glass microsphere (SGM)

Hybrid Composite

These are composites compounded with two or more reinforcements. The different types of hybrid composite are categorised as: (i) interplay or tow-by-tow where fibre constituent are in a regular or random manner. (ii) Sandwich, where layers of materials are sandwiched between one another. (iii) Laminated, here the alternate layers of various reinforcements are stacked piled in a regular manner. (iv) Intimately mixed, where the constituents are randomly mixed so as to abridge over-concentration of any constituent.

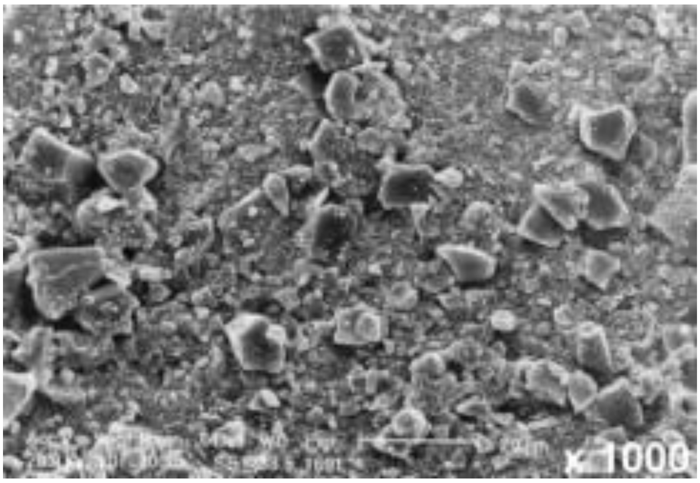

Fig 1.10: Hybrid composite resin

Hybrid concept is a simple extension of composite principle of combining more than one reinforcement, so as to optimise their values to the engineers, permitting exploitation of their less desirable properties. As such, the definition is much more sumptuary than reality. Any combination of dissimilar materials could be cogitated as a hybrid concept. A classic example is the type of structural material in which a metal or paper honeycomb or a rigid plastic foam is bonded to thin skins of some high-performance FRPS, the skin carrying the surface tensile and compressive load of the core providing lightweight and cheap structural stability.

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Chapter 2
Literature Review

Chapter 2

LITERATURE REVIEW

This literature review resembles the issues that were considered in this thesis and to accentuate the relevance of the present study. This formal exposition espouses some related aspects of polymer matrix composite with special attention to their Thermal/Dielectric characteristics. This topic comprises of brief follow-up of:

- Particulate Reinforced Hybrid Polymer Matrix Composites.
- Thermal conductivity of Polymer composites.
- Thermal conductivity models for Particulate composites.
- Dielectric behaviour of AlN/BN filled polymer composites.

On Particulate Filled Hybrid Polymer Composites

Incorporation of particulate fillers in a composite can have a strong influence on its mechanical response, such as 1) increasing stiffness of composite, 2) change strain history dependence on stiffness (cited as Mullins effect), 3) alteration in behaviours like hysteresis and stress relaxation. With miniaturisation of electronic devices emerging problems like heat dissipation difficulty and limiting reliability are often unriddled by using Polymer for electronic packaging or substrate material due to its high resistivity, low dielectric constant (D_k), however to counterbalance the poor thermal conductivity, thermally conductive and electrically insulating fillers like AlN or BN are used [4, 5]. These engineering composites are also desired due to low density, high corrosion resistance, ease of fabrication and low cost [15, 16, 17]. Along with fibre reinforcement, particulate reinforced composites have been ascertained as solution to many operational problems. Important roles in amelioration of electrical and thermal property of composites are brought in by intromission of AlN/BN into polymer matrix to form a composite [4, 5, 6].Currently, studies have focused on motleying properties of epoxy moulding compounds according to the type, size, shape, volume fraction and surface area of reinforced particle [6, 18 , 25].

On Thermal Conductivity of Polymer Composites

Thermal conductivity is one of the most important attribute of any particulate reinforced composite. Understanding the relationship between thermal conductivity and material microstructural properties (i.e. volume fraction, particle distribution, and individual filler property) has been a recent field of interest [1]. Polymer matrix such as epoxy resins have low thermal conductivity due to their stable chemical bonding and structure. Introduction of Nano-metallic fillers or fibres like single walled carbon nanotube (SWNTs), vapour-grown carbon nanofibres (VCNFs) are expected to demonstrate great propensity to possess high thermal conductivity in both fibre axis and in through-thickness direction, which can specifically produce high mechanical values [12]. Encompassing research are carried out to heighten the thermal conductivity of polymers by introduction of high thermal conductive fillers like metallic powders, carbon-based fillers or ceramic powders, inorganic fillers like Alumina (AL_2O_3), Silicon Nitride (Si_3N_4), Silicon Oxide (SiO_2), Boron Nitride (BN) etc. are also used. [5]. Thermal conductivity at interface plays a major role in heat transfer through the material [13]. In a research Xu et al. [14] found that composite exhibiting low values of dielectric constant and co-efficient of thermal expansion (CTE) are suitable for electronic packaging. Hence, polymer composites using epoxy resin or polyvinylidene fluoride (PVDF) used as matrix material and thermally conductive as well as electrically insulative reinforcements like aluminium nitride whiskers and/or silicon carbide whiskers are fabricated. It has been ascertained that effective thermal conductivity AlN particle (micro size ~ 115μm) epoxy matrix has increased by nearly 97%; also alteration in filler from AlN to SiC has enhanced the dielectric property [14]. In another research Zweifel [13] and Fennessey [13] utilised epoxy resin and powder (NX1) and platelets (HPCL) of Boron Nitride (BN – micro sized) and Silicon Carbide (SiC) as reinforcements, and has observed that thermal conductivity increases with increase in filler content and inclusion of 20 wt% of BN the thermal conductivity is best suitable for electrical application [13].

On Thermal Conductivity Models for Particulate Composites

Many theoretical and empirical models are proposed for prediction of effective thermal conductivity of a particle reinforced composites [19, 20]. For a hybrid composite, the simplest alternative is to arrange material either parallel or series with respect to heat flow.

For **parallel conduction** model

$$k_c = (1 - \emptyset_1 - \emptyset_2)\, k_m + \emptyset_1 k_{f1} + \emptyset_2 k_{f2} \qquad 2.1$$

where, $\mathbf{k_c}$, $\mathbf{k_m}$, $\mathbf{k_{f1}}$, $\mathbf{k_{f2}}$ are thermal conductivity of composite, material, 1st filler, 2nd filler, $\emptyset_1$, $\emptyset_2$ are volume fraction of 1st and 2nd filler respectively.

For **series conduction** model

$$\frac{1}{k_c} = \frac{1-\emptyset_1-\emptyset_2}{k_m} + \frac{1}{k_{f_1}} + \frac{1}{k_{f_2}} \qquad 2.2$$

For **geometric mean model**, also known as **Ratcliffe Empirical Model** gives the effective thermal conductivity as: [2]

$$k_c = k_m^{(1-\emptyset_1-\emptyset_2)} k_{f1}^{\emptyset_1} k_{f2}^{\emptyset_2} \qquad 2.3$$

Russell has obtained a theoretical conductivity model using series parallel network, assuming similar sizes of cubes and pores, and the isothermal lines are planes. [2].

$$k_c = k_m \left[\frac{\emptyset^{2/3} + \frac{k_m}{k_f}\left(1-\emptyset^{2/3}\right)}{\emptyset^{2/3} - \emptyset + \frac{k_m}{k_f}\left(1+\emptyset+\emptyset^{2/3}\right)} \right] \qquad 2.4$$

Modifying Halpin – Tsai equation **Lewis and Nielsen** gave a semi-theoretical which includes shape of particle and orientation in two phase system.

$$k_c = k_m \left[\frac{1 + AB\emptyset}{1 - B\emptyset\Psi}\right] \quad 2.5$$

where, $B = \left[\frac{(k_f/k_m)-1}{(k_f/k_m)+A}\right]$ and, $\Psi = 1 + \left[\frac{1-\emptyset_m}{\emptyset_m^2}\right]$

where, k_f is thermal conductivity of filler material

$\emptyset$ is the volume fraction of filler material

The value of A and $\emptyset_m$ for different shapes are provided in table.

Table 2.1: Value of A for various systems

Type of dispersed phase	**Direction of heat flow**	**A**
Cubes	Any	2
Spheres	Any	1.5
Aggregates of spheres	Any	$(2.5/\emptyset_m) - 1$
Randomly oriented rods Aspect ratio=2	Any	1.58
Randomly oriented rods Aspect ratio=4	Any	2.08
Randomly oriented rods Aspect ratio=6	Any	2.8
Randomly oriented rods Aspect ratio=10	Any	4.93
Randomly oriented rods Aspect ratio=15	Any	8.38
Uniaxially oriented fibres	Parallel to fibres	2L/D
Uniaxially oriented fibres	Perpendicular to fibres	0.5

Table 2.2: Value of $\emptyset_m$ for various systems

Shape of particle	**Type of packing**	**$\emptyset_m$**
Spheres	Hexagonal close	0.7405
Spheres	Face centred cubic	0.7405
Spheres	Body centred cubic	0.60
Spheres	Simple cubic	0.524
Spheres	Random close	0.637
Rods and fibres	Uniaxial hexagonal close	0.907
Rods and fibres	Uniaxial simple cubic	0.785
Rods and fibres	Uniaxial random	0.82
Rods and fibres	Three dimensional random	0.52

Agari and Uno proposed a model blended with both series and parallel conduction mechanisms. The conductivity governing expression is given as: [3]

$$\log k_c = \emptyset C2 \log k_f + (1 - \emptyset) \log(C1. k_m) \qquad 2.6$$

Where, $C_{1,}$ C_2 are experimentally determined.

C_1 is the measure of particle effect on crystallinity and crystal size of polymer.

C_2 is the conductive chain formation potentiality of the particles.

For infinitely dilute composite of spherical particulate reinforcement particulates randomly dispersed and devoid of mutual interaction in homogeneous medium, **Maxwell** has obtained exact expression for thermal conductivity, using Potential theory [3, 21].

$$k_c = k_m \left[\frac{kf + 2km + 2\emptyset(kf - km)}{kf + 2km - 2\emptyset(kf - km)}\right] \qquad 2.7$$

Only for dilute suspension of sphere for homogeneous medium **Bruggeman** derived the equation employing different assumptions for permeability and field strength. [2].the implicit equation given as:

$$1 - \emptyset = \left[\frac{k_c - k_f}{k_m - k_f}\right] \left(\frac{k_m}{k_c}\right)^{1/3} \qquad 2.8$$

On Dielectric property of AlN/BN filled Polymer Composite

Epoxy resins are considered materials with excellent mechanical, electrical property along with good chemical stability [7]. Advancement in electronic and electrical technology has led component integration into single device to increase functionality and performance enhancement [4]. In a recent research Gao et al. [7] found the necessity of epoxy resins to be utilised as an insulator in such electrical machinery and electronic devices and as packaging or substrate material for integrated circuits due to its low dielectric value [7]. Wireless communication evolution has gratified personal communication necessity to a larger scale, integrating various active and passive electronic components which in-turn takes up large area lowering electrical performance due to solder joints. Henceforth study of dielectric material with high performance and stable characteristic is of interest for recent research areas [8]. In a research Wu et al. [8] found that epoxy resin due to its inertness is found suitable for electroless plating solution and is compatible to printed wiring board (PWB). Hence, epoxy due to its process mixing ability with high dielectric constant ceramics is of great interest for electromagnetic band-gap (EBG) substrate and in embedded devices [8, 26, 27].

Objective of the present investigation

The objectives are outlined below:

- Fabrication of a composite using micro-sized (100μm) solid glass microsphere (SGM) as particulate reinforcement.
- Experimental determination of the dielectric constant values ($\mathbf{D_k}$) in the frequency range of 1 kHz to 1000 kHz and the effective thermal conductivity (**K**) of these particle filled composites (for different volume fraction).
- Estimation of equivalent thermal conductivity (**K**) using different thermal conductivity models as stated in the literature review.
- Fabrication of a hybrid composite using both micro-sized SGM as well as boron nitride (BN) as filler particles.
- Experimental measurement of the dielectric constant values ($\mathbf{D_k}$) in the frequency range of 1 kHz to 1000 kHz and the effective thermal conductivity (**K**) of these particle filled composites (for different volume fraction).

Chapter Summary

This chapter has presented a brief summary on the research history related to the issues of particulate filled polymer composites. It has also thrown light on various existing models for determination of effective thermal conductivity of such composites. The next chapter depicts the materials used and the methods followed while carrying out this investigation.

******

Chapter 3
Materials and Methods

Chapter 3

MATERIALS AND METHODS

The manufacturing process of the composites under probe along with the materials and test methods used for fabrication are delineated in this segment. This section showcases the details of thermal and dielectric characterisation tests which the hybrid composite are subjected to. The numerical methodology colligated for the determination of thermal conductivity based on finite element method is also presented in this segment.

NUMERICAL ANALYSIS

Concept of Finite Element Method (FEM) and ANSYS

Finite Element Method (FEM), introduced originally by Turner et al. [22] 1956, has great proficiency to obtain approximate solution to variety of “real-world” engineering problems having complexities subjected to general boundary conditions. FEM is now the vital step in design or modelling of various physical phenomenons, which typically occurs in continuum of matter involving several field variables. The field variable varies over points, thereby possessing infinite number of solutions in the domain.

The concept of FEM banks on the decomposition of domain into finite number of sub-domains (i.e. Elements) for synthesis of systematic approximate solution by variational or residual weighted method. FEM reduces the problem by parting the domain into finite number of unknown elements by expressing the unknown field variable in terms of assumed approximation function (also called interpolation function). Nodes located along element boundary connect the adjacent element. The discretisation of irregular domain makes this method a practical analyser tool for boundary solutions. Thus, FEM is a numerical procedure for solving engineering problems involving heat transfer, stress analysis, fluid flow etc.

Basic Steps of FEM

The governing differential equation is first converted into an integral form, achieved by two different techniques:

- Variational Technique
- Weighted Residual Technique

In variational technique calculus of variation is utilised to obtain integrals from given differential equations. Minimisation of integral is required to obtain solution.

In weighted residual technique, weighted integral are constructed of governing differential equation where weight fractions are known and give arbitrary values, except those satisfying boundary conditions. For reduction of continuity requirement of solution, often integrals are modified using divergence theorem, and by setting the integral to zero solution are obtained.

In second step, the domain is divided into number of parts called elements. For one-dimensional (1 – D) problem elements are line segments with no shape and only length. For two-dimensional (2 – D) or axi-symmetric problems, triangular, rectangular or quadrilateral elements are used with curved or straight boundary. In three-dimensional (3 – D) problems tetrahedron or parallelepiped elements are used. Division of domain into elements is known as mesh.

In third step, suitable approximation chosen over an element as primary variable for interpolation function (also called shape function), and unknown values of primary variable at some pre-selected points known as nodes. Polynomials are basically chosen as shape functions. For 1 – D elements, 2 nodes are placed at end points, while for 2 – D and 3 – D nodes are placed at vertices. Additional nodes are placed either on boundary or interior, and the primary values at these nodes are called as degree of freedom.

Primary variable must contain a complete set of polynomial for exact solution or may contain finite terms, then elements will be infinite, hence, both cases results in infinite set of algebraic equations. To make the problem manipulable, finite number of elements with expressions with finite number of terms is used. The approximate solution accuracy can be improved by raising the number of elements or the number of terms of approximation.

In forth step, primary variable of approximation is substituted into integral form. Further, the integrals are minimised to get algebraic equations for unknown nodal values. First algebraic equations are obtained element wise (known as the element equation) and further assembled over elements to obtain equation for whole domain (known as global equation).

In the last step, solution post-processing is done. Secondary variable are first measured, then nodal value of primary and secondary are utilised to construct graphical variation over domain in the form of graph of different dimension and contour.

Advantages of finite element method over several other numerical methods:

- Irregular shaped domain with several different types of boundary conditions can be analysed.
- Multiple numbers of domains can be easily analysed.
- Solution accuracy can be improved either by choosing approximation of higher degree polynomial or by proper refinement of mesh.
- Generated algebraic problems can be easily solved in computer; also general purpose code developed can assist analysis of large class problems.

EXPERIMENTAL DETAILS

Matrix Material:

Epoxy resin procured from Ciba-Geigy India Ltd. is utilised as a matrix material for the present research. Epoxy (LY 556) resin which is chemically form ‘epoxide’ family is the matrix material. Low temperature curing epoxy resin (LY 556) and araldite hardener (HY 951) are mixed in 10:1 ratio as recommended. Epoxy is chosen due to its low density (1.1 gm/cc).

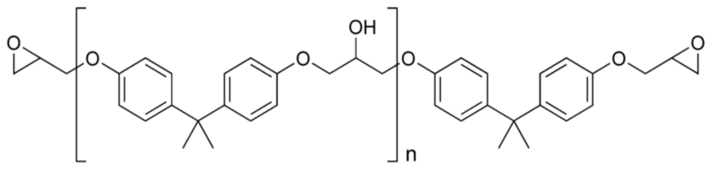

Fig 3.1: Unmodified epoxy prepolymer resin chain

(‘**n**’ denotes number of polymerised unit)

Fig 3.2: Epoxy Resin

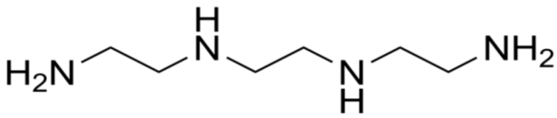

Fig 3.3: Triethylene tetramine (Hardener used for epoxy matrix)

Filler Material - 1: (Solid Glass Micro-spheres)

Micro-sized solid glass microspheres (approximately ≈ 100 µm, procured from NICE Ltd., Mumbai) obtained by heating tiny droplets of dissolved sodium metasilicate (Na_2SiO_3, commonly referred to as water glass or liquid glass) during ultrasonic spray pyrolysis process, is used as reinforcement for this present investigation. Glass microsphere which varies from a range of 1 to 1000 µm also with a very low density (1.5 gm/cc) as well as low thermal conductivity (0.04 W/m.k) is a suitable material for providing the desired low dielectric constant (**D$_k$**) value.

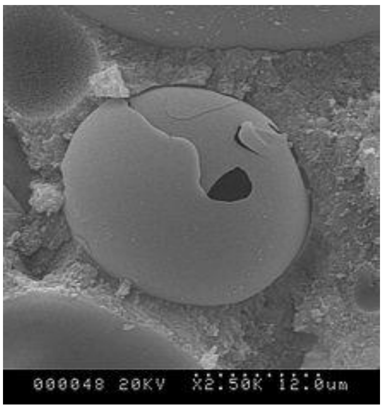

Fig 3.4: SEM structure of solid glass microsphere

Filler Material - 2: (Boron Nitride)

Micro-sized Boron Nitride (BN) powder (procured from NICE Ltd., Mumbai) acquired synthetically from of boric acid (H_3BO_3) and boron trioxide (B_2O_3) is also used as filler reinforcement. The hexagonal form of boron nitride (h-BN or α-BN) is the most stable crystalline form with a melting point as high as 2973°C. Also, its layer structure as of graphite, and each layer covalently bonded together makes it electrically insulating and its high thermal conductivity (110 W/m.k) makes it a perfect suit for the required purpose.

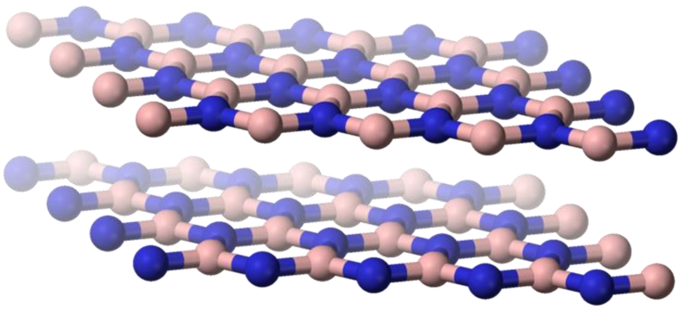

Fig 3.5: Hexagonal crystalline form of Boron Nitride (h-BN or α-BN)

Composite Fabrication

Micro-sized solid glass micro-spheres as well as boron nitride are mixed in different weight fractions [29], in different proportions as bespoken below. Along with the epoxy resin and particulate reinforcement, Triethylene Tetramine (TETA, Araldite HY 951) was utilised as hardener in proper proportion for fabrication.

Table 3.1: List of particulate filled hybrid composite fabricated by hand-lay-up technique

Sample	Composition
1	Epoxy + 5.638 wt% (8.26 vol%) SGM
2	Epoxy + 10.013 wt% (14.29 vol%) SGM
3	Epoxy + 15.163 wt% (21.10 vol%) SGM
4	Epoxy + 19.974 wt% (27.31 vol%) SGM
5	Epoxy + 20.325 wt% (26.23 vol%) SGM + 5.020 wt% (9.92 vol%) BN
6	Epoxy + 20.150 wt% (24.50 vol%) SGM+ 10.056 wt% (18.72 vol%) BN

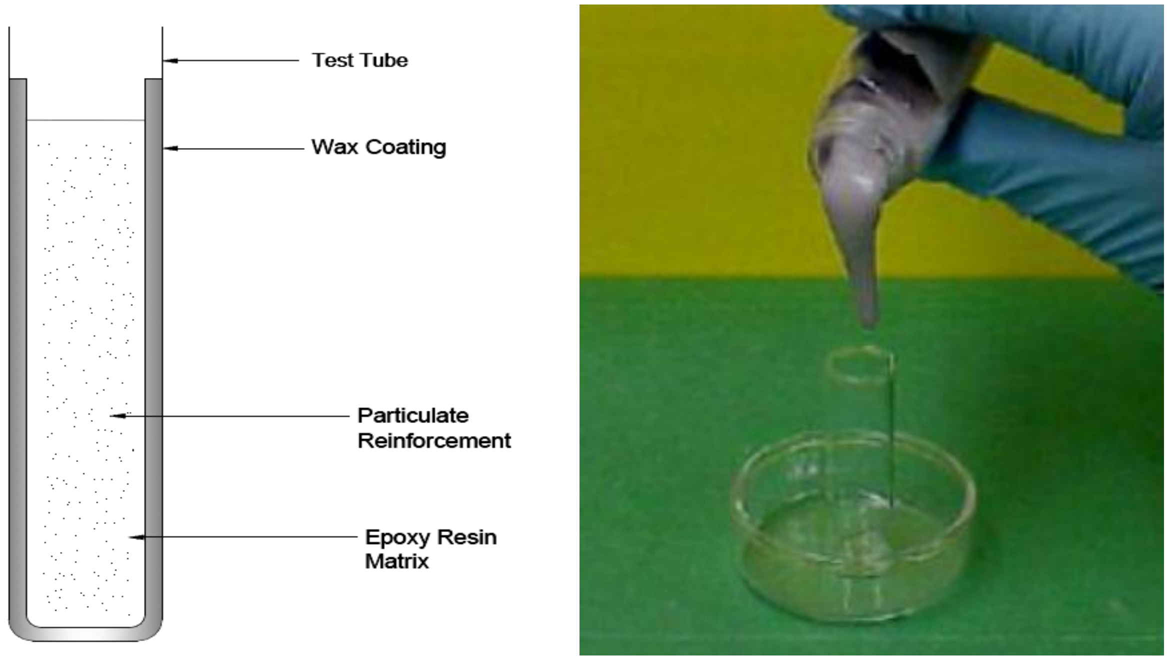

Fig 3.6: Particulate Reinforced composite fabrication using Hand-lay-up technique.

Experimental Determination of Thermal Conductivity

Unitherm™ Model 2022 is used to measure thermal conductivity of various materials, which include polymers, glasses, ceramics, rubbers, composites, few metals and other material with medium to low thermal conductivity. Fluid or semi-fluids like paste etc. can be tested using a special container. Employing multilayer technique thin films can also be tested. This test is in accordance with **ASTM E-1530** standards.

Operating Principle of Unitherm™ 2022

The material is held under uniform compressive load between two polished surfaces, controlling each sample at a different temperature. The lower surface is part of a calibrated heat flow transducer. Heat flow directs from upper surface through sample to lower surface, establishing axial temperature gradient in stack. On reaching thermal equilibrium, temperature difference across the sample surfaces is assessed along with heat flow transducer output. The sample thickness value is then measured and used to estimate thermal conductivity. The temperature drop through sample is measured using sensors on metal surface layers on either side.

Fig 3.7: Thermal Conductivity measuring instrument Unitherm™ 2022

By definition "Thermal conductivity is the exchange of energy between adjacent molecules and electrons in a conducting medium, it is a material property that describes heat flow within a body for a given temperature difference per unit area."

For one-dimension heat flow the equation is given as:

$$Q = \kappa A \frac{T_1 - T_2}{x} \tag{3.1}$$

Where, **Q** is the one – dimensional heat flow (W), **A** is the cross-sectional area (m^2), **κ** is thermal conductivity (W/m.k), **x** is the sample thickness (m), $\mathbf{T_1 - T_2}$ is the temperature difference between surfaces (°C or K).

The thermal resistance of the sample is given as:

$$R = \frac{T_1 - T_2}{QA} \tag{3.2}$$

Where, **R** is sample resistance between hot and cold surfaces ($m^2.K / W$)

From the former equation we can write

$$\kappa = \frac{x}{R} \qquad 3.3$$

In Unitherm™ 2022, transducers measure value of heat flux Q and temperature difference between upper and lower plate. Thus thermal resistance between surfaces can be evaluated. Providing different thickness and known cross-sectional area as input parameters, the sample thermal conductivity can be calculated.

Dielectric Measurement

Using Hioki 3532-50 Hi - Tester LCR analyser with applied voltage of 500 mV and in frequency range 1 kHz – 1 MHz, the dielectric constant (**D_k**) can be calculated from capacitance by:

$$D_k = Ct/\varepsilon_0 A \qquad 3.4$$

Where, **t** is the thickness of disks

ε_0 is the electrical permittivity of free space.

A is the disk area.

Fig 3.8: Hioki 3532-50 LCR Hi tester

The used samples were disk shaped with both surfaces aluminium foil wrapped.

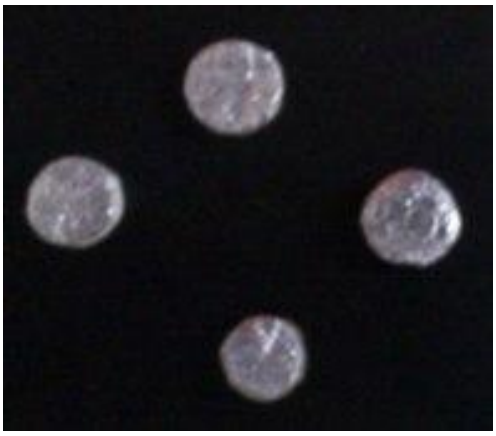

Fig 3.8: Aluminium foil wrapped test samples for dielectric test.

Fig 3.9: SGM filled Epoxy composite (left) and SGM + BN filled Epoxy composite (right)

Chapter Summary

Point described in this section are summarised as:

- Description of material used for experiments.
- Hand-lay-up technique details for fabrication of composite.
- Description of thermal conductivity and dielectric property measurement

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Chapter 4
Results and Discussion

Chapter 4

Results and discussion

Numerical Analysis

Using the finite-element program ANSYS, thermal analysis of conductive heat transfer through the composite body is carried out. In order to make this analysis, three-dimensional physical models, spheres-in-cube lattice arrays have been used to simulate the microstructure of composite materials for variable filler concentrations [25]. Moreover, the effective thermal conductivities (**k_{eff}**) of these epoxy composites filled [25] with SGB up to about **27.31%** by volume were numerically determined using ANSYS.

Description of the problem

The determination of effective properties of composites is of preponderating importance for functional design and application of composite materials. One of the important factors that influence the effective properties and can be controlled to an appreciable extent is the microstructure of the composite. Here, microstructure means the shape, particle size distribution, spatial distribution and orientation distribution of the reinforcing inclusion in the matrix. Although most composite possess inclusion of random distributions, great perceptiveness of the effect of microstructure on the effective properties can be gained from the investigation of composites with periodic structure. System with periodic structures can be more easily analysed because of the high degree of symmetry embedded in the system. A typical periodic arrangement of solid glass microsphere within the epoxy resin is schematically shown in Fig. **4.1** and Fig. **4.2**; clearly exemplifying the heat flow direction and the boundary conditions for the particulate – polymer composite body viewed for the analysis of this thermal problem. The temperature at the nodes along the surfaces ABCD is prescribed as T_1 (=100^0C) and the ambient convective heat transfer coefficient is assumed to be 2.5 W/m^2-K at room temperature of 27°C. The other surfaces parallel to the heat flow direction are all assumed to be isentropic. The temperatures at the nodes in the interior region and on the other boundaries are obscure. These temperatures are obtained with the help of the finite-element program package ANSYS. It is assumed in this analysis that the composites are macroscopically homogeneous, locally both the matrix and filler are homogeneous and isotropic, the thermal contact resistance between the filler and the matrix is negligible and the composite lamina is free from voids. The problem is based on 3 – D physical model and the filler arranged in a square periodic array are assumed to be uniformly distributed in the matrix.

Assumptions

During analysis of the ideal case it will be assumed that

- Composites are reckoned as macroscopically homogeneous.
- Both the matrix and filler are topically homogeneous and isotropic.
- The thermal contact resistance between the filler and the matrix is considered negligible.
- The composite lamina is deficient of voids.
- The problem is three – dimension based physical model.
- Reinforced particles are in square periodic array or uniformly dispersed.

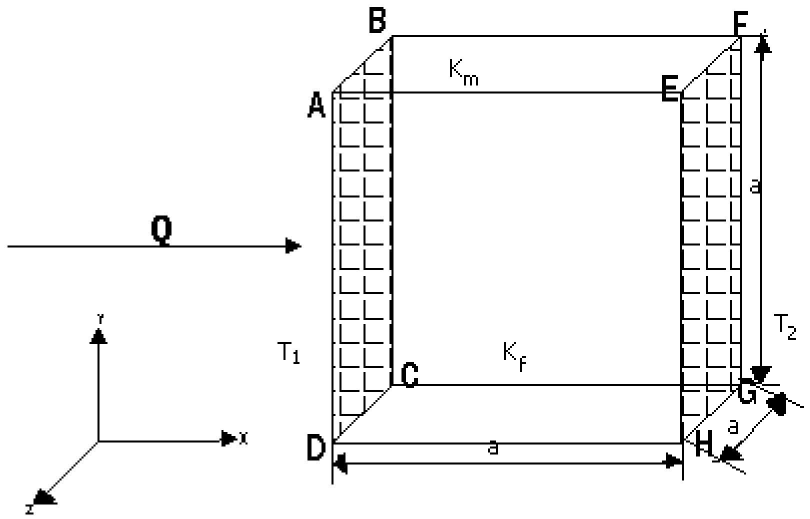

Fig 4.1: Boundary Condition

Using the spheres-in-cube model the thermal conductivities (**k_{eff}**) of these SGB-epoxy composites are numerically estimated. A typical 3-D model showing arrangement of spherical fillers with a particle concentration of 8.26 vol% within the cube shaped matrix body is illustrated in Fig. **4.2**; The temperature profiles obtained from FEA analysis for the composites with particulate concentrations of **8.26, 14.29, 21.10** and **27.31 vol %** are presented in Figs: **4.3, 4.4, 4.5, 4.6** respectively. The simulated values of effective thermal conductivity ($\mathbf{k_{eff}}$) of the composites obtained from FEA along with the corresponding measured values of **'$\mathbf{k_{eff}}$'** are presented in Table: **4.1**. The percentage errors associated with the FEA values with respect to the experimental values are also given in Table: **4.2**. It is noted that the results obtained from the FEA taking sphere-in-cube composite model are reasonably closer to the measured values of effective thermal conductivity ($\mathbf{k_{eff}}$) for composites of dissimilar filler content. On comparing, it is further noticed that FEA underestimates the value of thermal conductivity, with respect to the experimental ones. However, it leads to a conclusion that for a particle filled composite of this kind the finite element analysis can very well be used for prognostic purpose in determining the effective thermal conductivity for a broad range of particle concentration.

Fig. 4.9 presents the variation of effective thermal conductivity (both simulated as well as measured) as a function of the SGB content in the composites. The difference between the feigned values and the computed value of conductivity may be attributed to the fact that some of the assumptions taken for the numerical analysis are not real. The distribution of SGB in the matrix body in the numerical analysis is assumed to be in an arranged manner, however in the fabricated composite sample, the glass beads are actually dispersed in the resin almost randomly. However, it is encouraging to note that the incorporation of SGM upshots in significant drop in thermal conductivity of epoxy resin. With addition of **8.26 vol%** of SGB, the thermal conductivity decreases by about **22.03 %** and with addition of **27.31 vol%** of SGB the thermal conductivity decreases by about **42.97 %** when compared with neat epoxy resin.

Similarly, the thermal conductivity values for SGM + BN Epoxy composites are estimated using sphere-in-cube model. A typical 3-D model showing arrangement of spherical fillers with a particle concentration of **26.23** vol% of SGM, **9.92** vol% of BN and **24.5** vol% of SGM, **18.72** vol% of BN a within the cube shaped matrix body, and the resultant temperature profile are presented in fig: **4.7** and Fig: **4.8**.

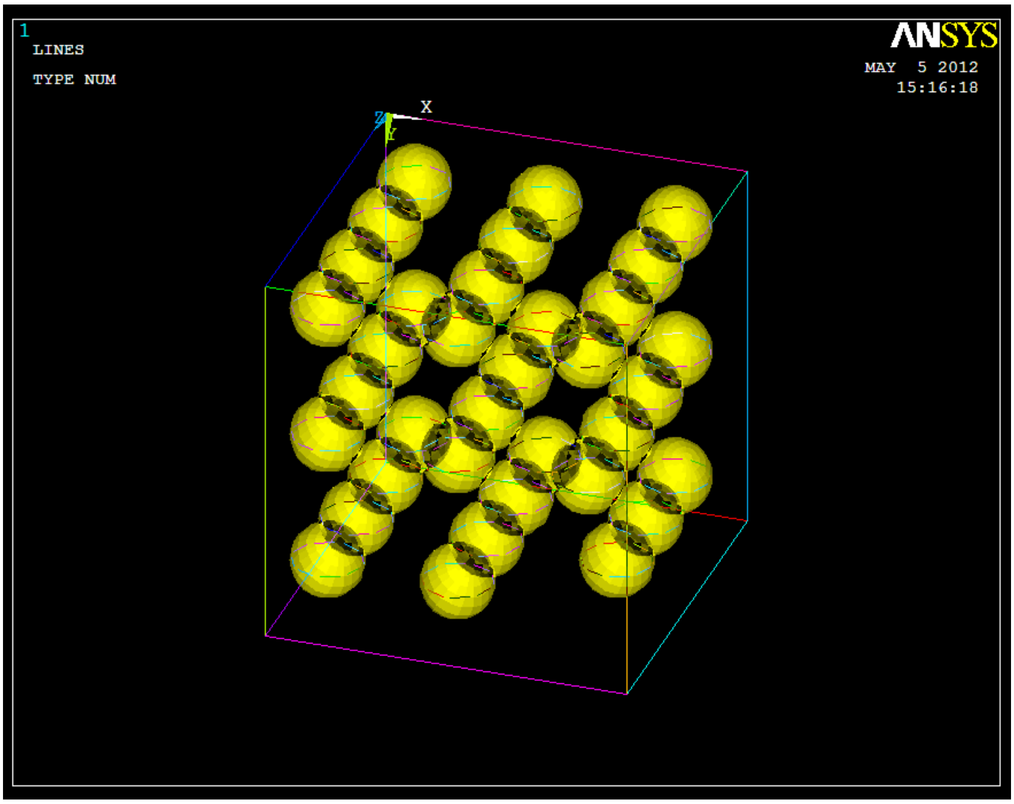

Fig 4.2: Typical spheres-in-cube model with SGM content 8.62 vol%

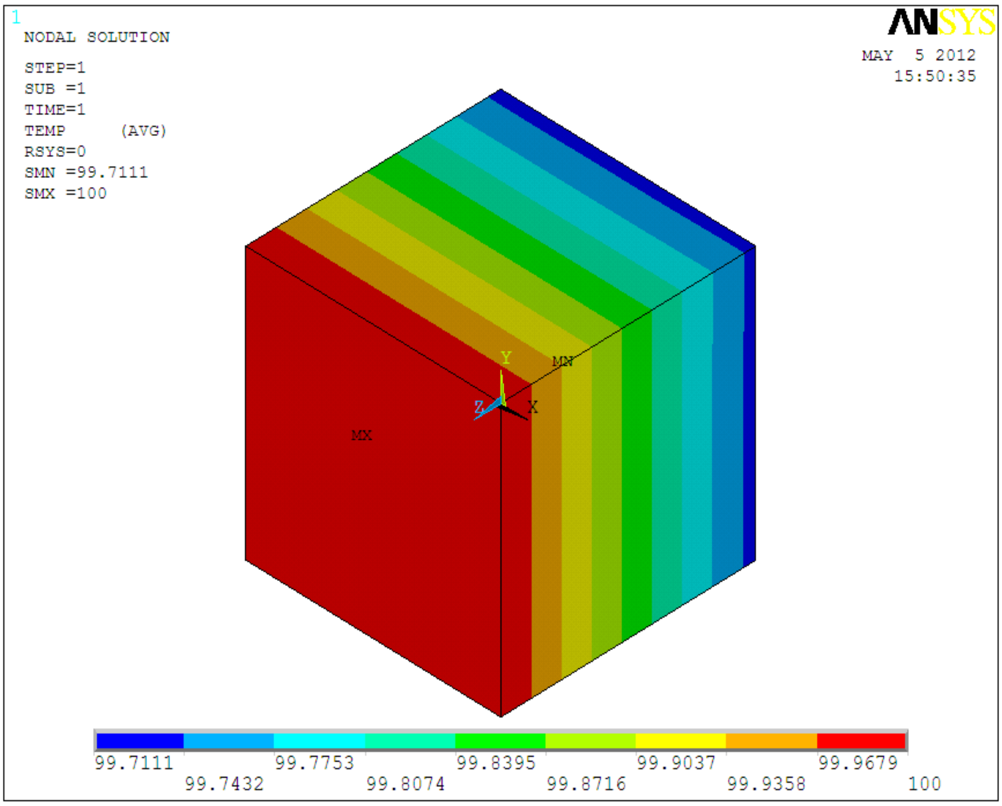

Fig 4.3: Temperature profile for SGM-Epoxy composite for particle concentration 8.26 vol%

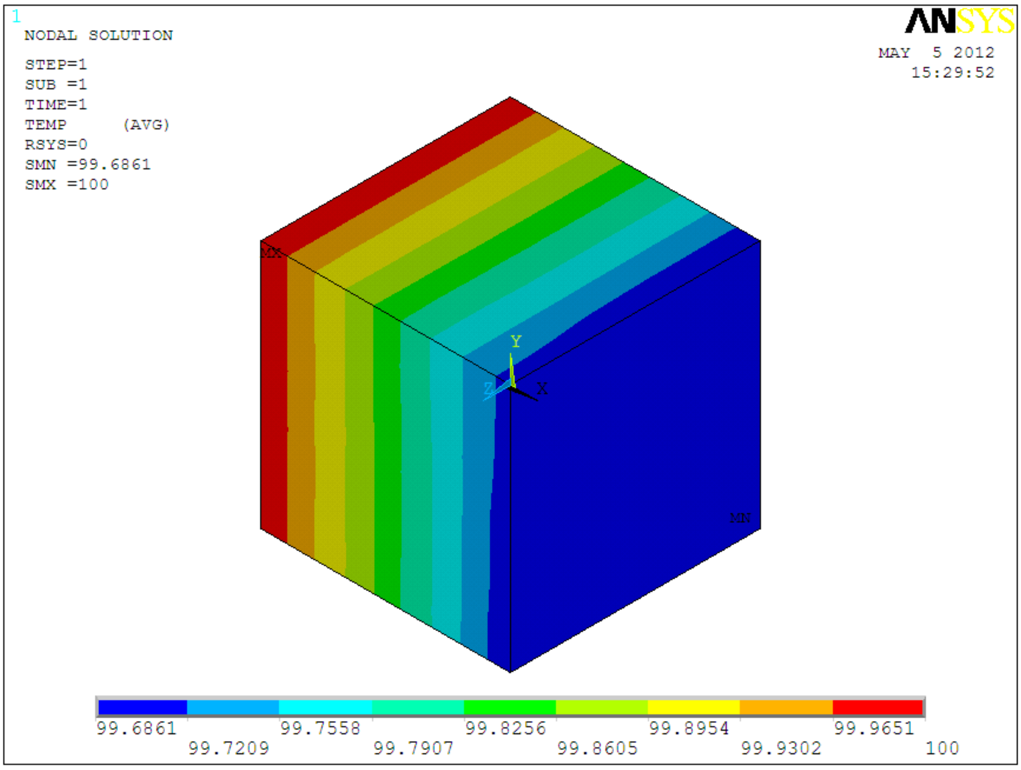

Fig 4.4: Temperature profile for SGM-Epoxy composite for particle concentration 14.29 vol%

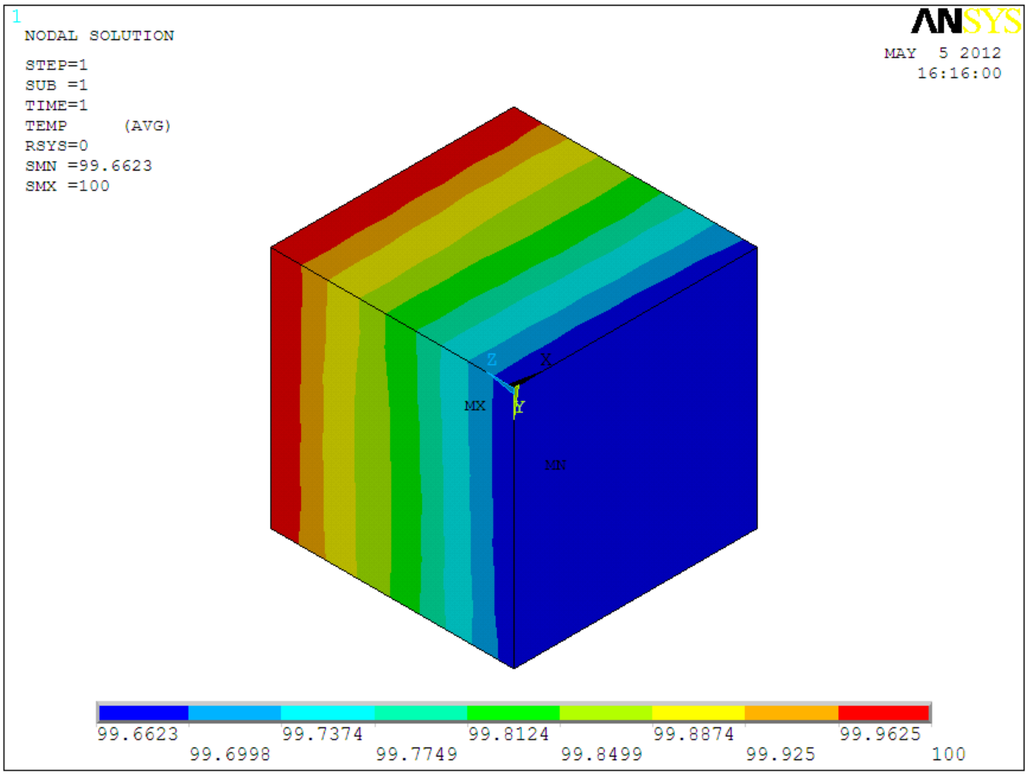

Fig 4.5: Temperature profile for SGM-Epoxy composite for particle concentration 21.10 vol%

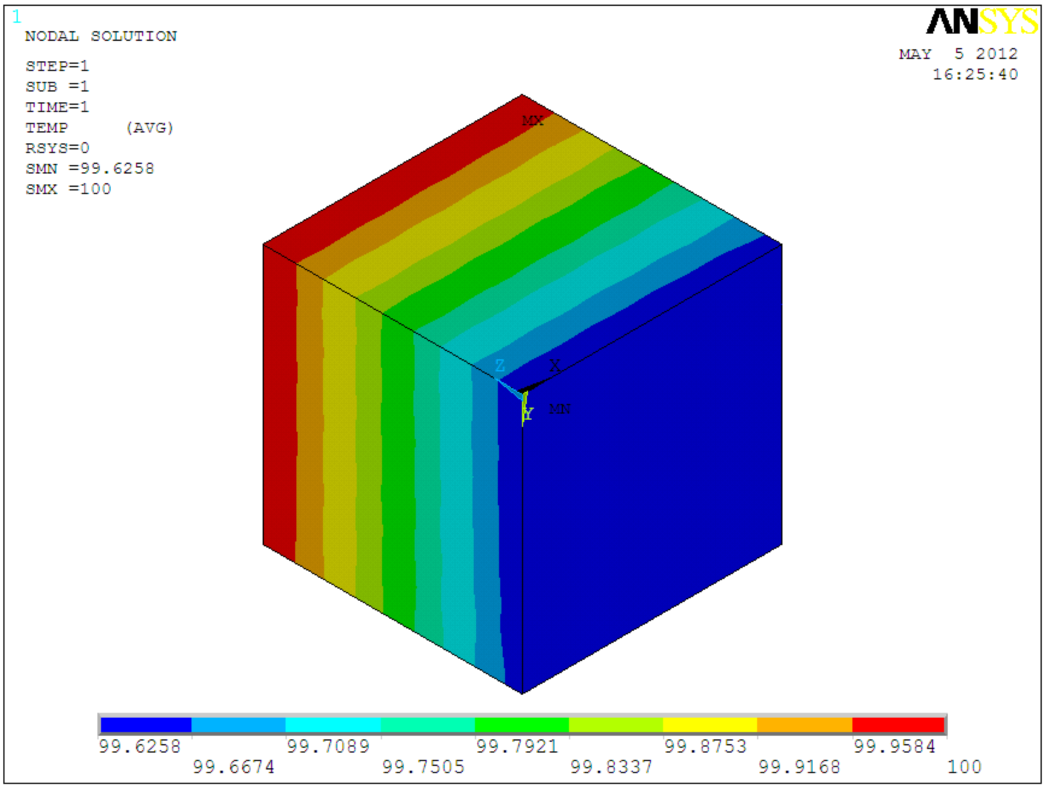

Fig 4.6: Temperature profile for SGM-Epoxy composite for particle concentration 27.31 vol%

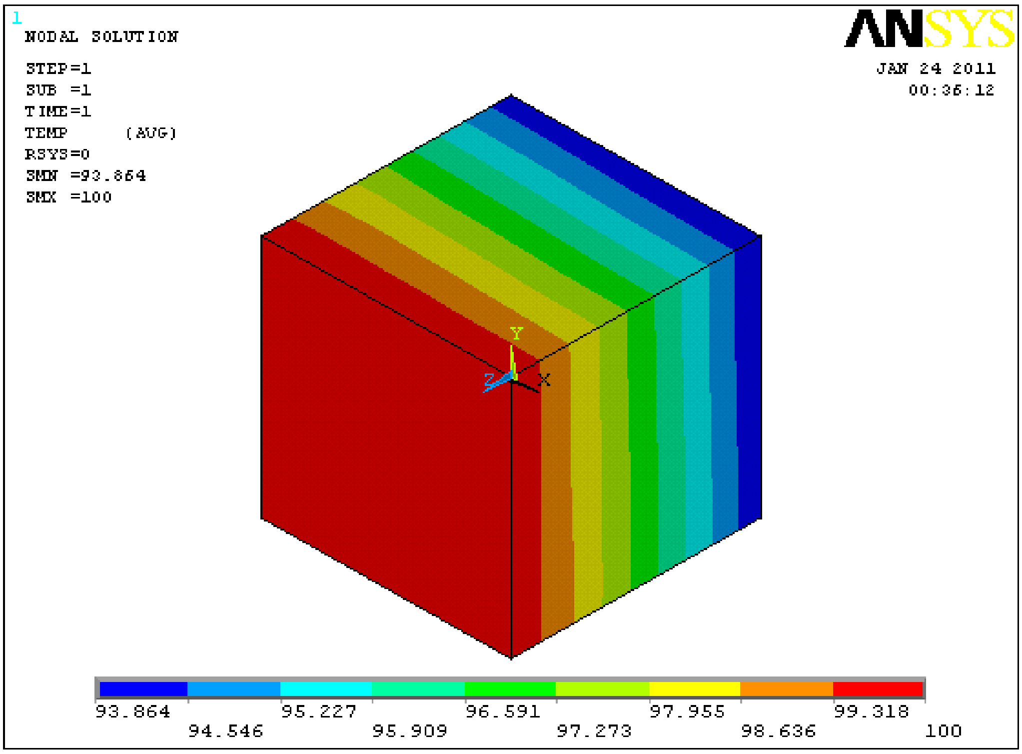

Fig 4.7: Temperature profile for SGM-BN-Epoxy composite for particle concentration 26.23 vol% SGM and 9.92 vol% BN

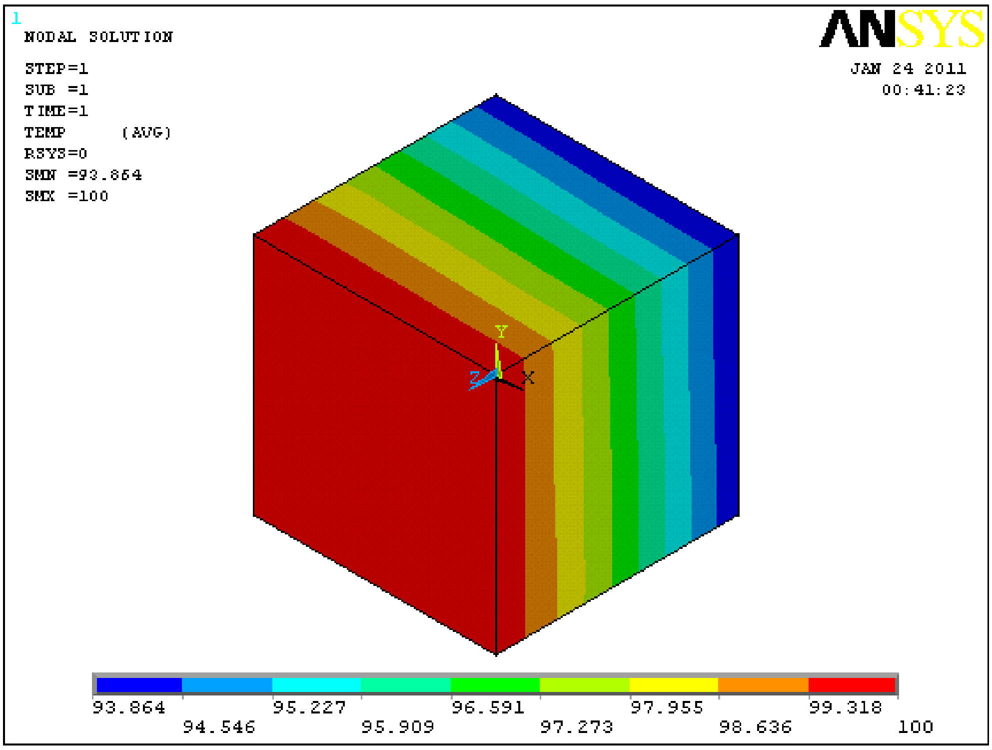

Fig 4.8: Temperature profile for SGM-BN-Epoxy composite for particle concentration 24.5 vol% SGM and 18.72 vol% BN

The effective thermal conductivity (**k$_{eff}$**) values of the particulate reinforced epoxy composite with various proportions of SGM and SGM + BN content are obtained using from existing theoretical models, such as Rule of Mixture, Maxwell's equation, Lewis and Nielson's model and Ratcliffe's model, and are presented in Table: 4.1 . It presents a competitive picture of thermal conductivity values obtained from finite element method as well as experimental values. The thermal conductivity values obtained from FEM are in concurrence with the experimental values than those values calculated from existing theoretical models.

Table 4.1: Effective thermal conductivity (k_{eff}) of composites obtained from different methods.

Sample No.	Volume %	Weight %	Rule of Mixture Model	Ratcliffe Empirical Model	Maxwell's Model	Lewis & Nielsen Model	Experimental	FEM
1	8.26	5.638	0.336	0.303	0.326	0.323	0.283	0.3157
2	14.29	10.013	0.317	0.265	0.301	0.295	0.261	0.2907
3	21.10	15.163	0.295	0.228	0.274	0.265	0.234	0.2702
4	27.31	19.974	0.275	0.199	0.251	0.239	0.207	0.2439

Table 4.2: Percentage error of different models with respect to experimental values

Sample no.	Volume %	Weight %	Rule of Mixture Model	Ratcliffe Empirical Model	Maxwell's Model	Lewis & Nielsen Model
1	8.26	5.638	18.72	7.06	15.19	14.13
2	14.29	10.013	21.45	1.53	15.32	13.03
3	21.10	15.163	26.06	-2.56	17.09	13.25
4	27.31	19.974	32.85	-3.86	21.26	15.46

Table 4.3: Percentage error of FEM analysis with respect to experimental values

Sample no	Volume%	Weight%	FEM (% errors)
1	8.26	5.638	11.55
2	14.29	10.013	11.37
3	21.10	15.163	15.47
4	27.31	19.974	17.82

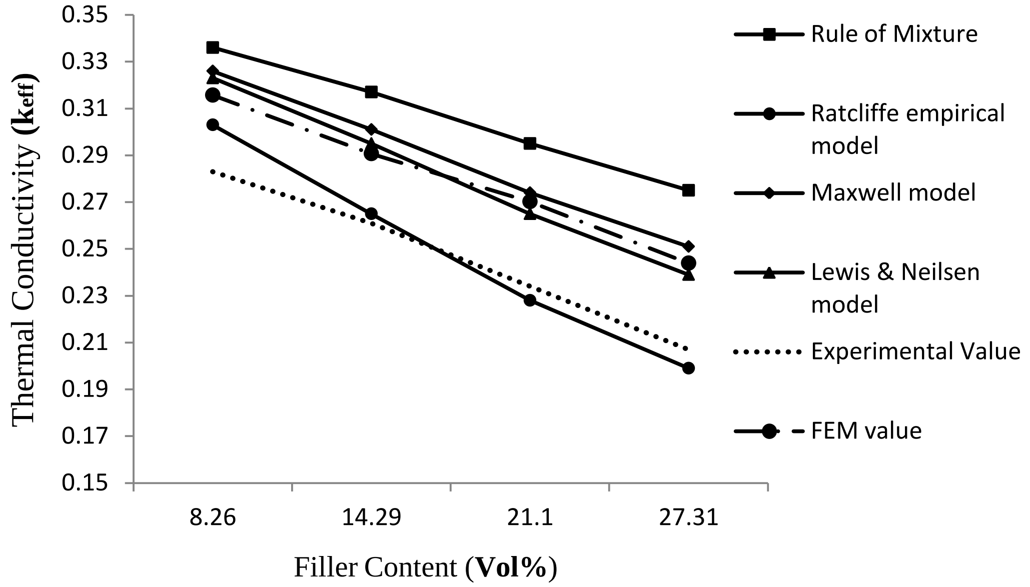

Fig 4.9: Values of thermal conductivity with respect to filler content for different models

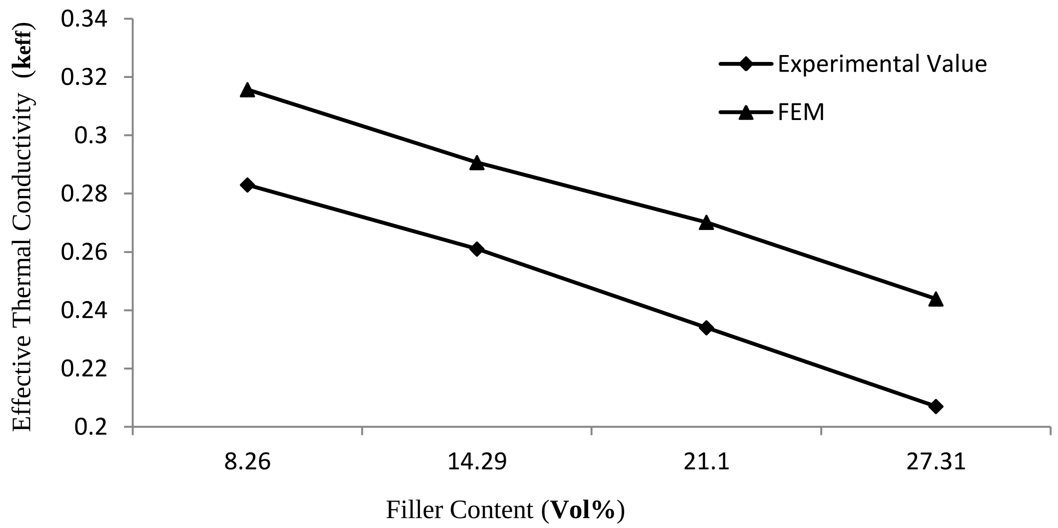

Fig 4.10: Variation of thermal conductivity of composites as a function of SGM content

On comparison with experimentally measured values for SGM filled Epoxy composites, it is further noticed that FEM values underestimate the value of thermal conductivity whereas Rule of Mixture, Maxwell’s equation, Lewis and Nielson’s model and Ratcliffe’s models overestimate the value of thermal conductivity. It leads to a conclusion that for a particulate filled composite the FEM (sphere-in-cube model) can very well be used for anticipating effective thermal conductivity for a wide range of particle concentration.

DIELECTRIC PROPERTY OF SGM-BN FILLED EPOXY COMPOSITE

Dielectric Constant (D_k)

For Zero frequency the relative permittivity of a material is known as its static relative permittivity or as its dielectric constant (**D_k**). Relative permittivity or dielectric constant is denoted as the ratio of complex frequency – dependent absolute permittivity of material, '**ε**' to the vacuum permittivity, '**ε_0**', so $D_k = \varepsilon/\varepsilon_0$. '**$D_k$**' being a ratio of two similar quantities, it is a dimensionless value. Any material has polarisation capacity more than vacuum; hence, the **D_k** of any material is always greater than 1. It is also function of frequency for some polymers, principally because of the effect of polarisation on frequency. In the present research, dielectric constant (**D_k**) measurement are taken on Hioki 3532-50 Hi – Tester LCR analyser with applied voltage of 500 mV. The frequency range varies from 1 kHz – 1000 kHz. Fig: shows curve representing values of dielectric constant as a function of frequency. As indicated by the figures irrespective of material composition '**D_k**' value decrease with increasing frequency. Such behaviour was also reported by some previous investigators for epoxy resin based composite [21, 23, 24].

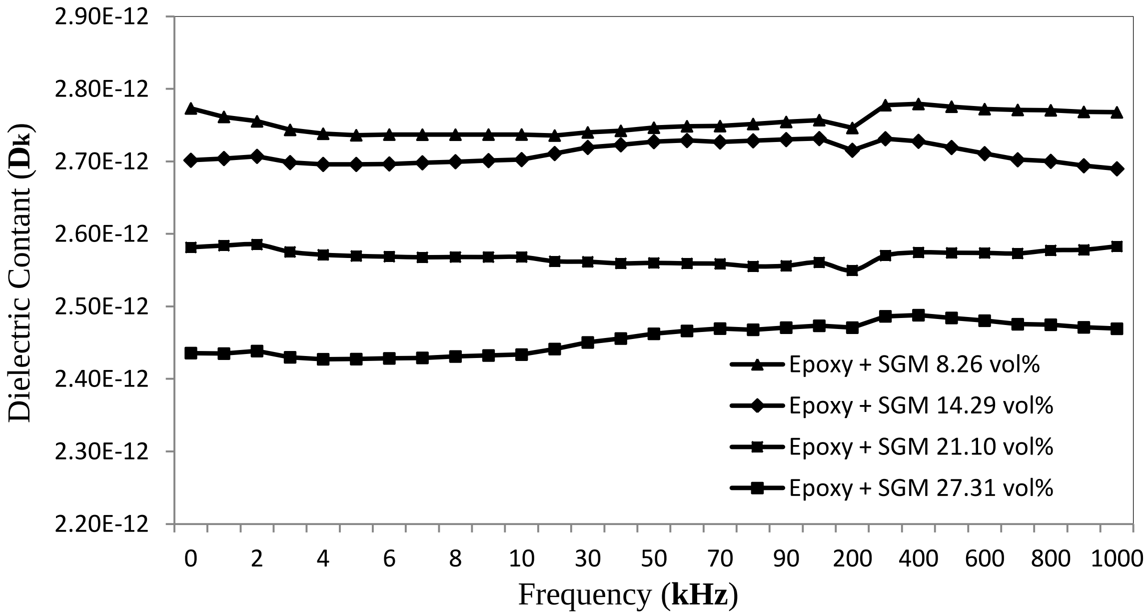

Fig 4.11: Variation of Dielectric constant as a function of Frequency for SGM filled epoxy composite

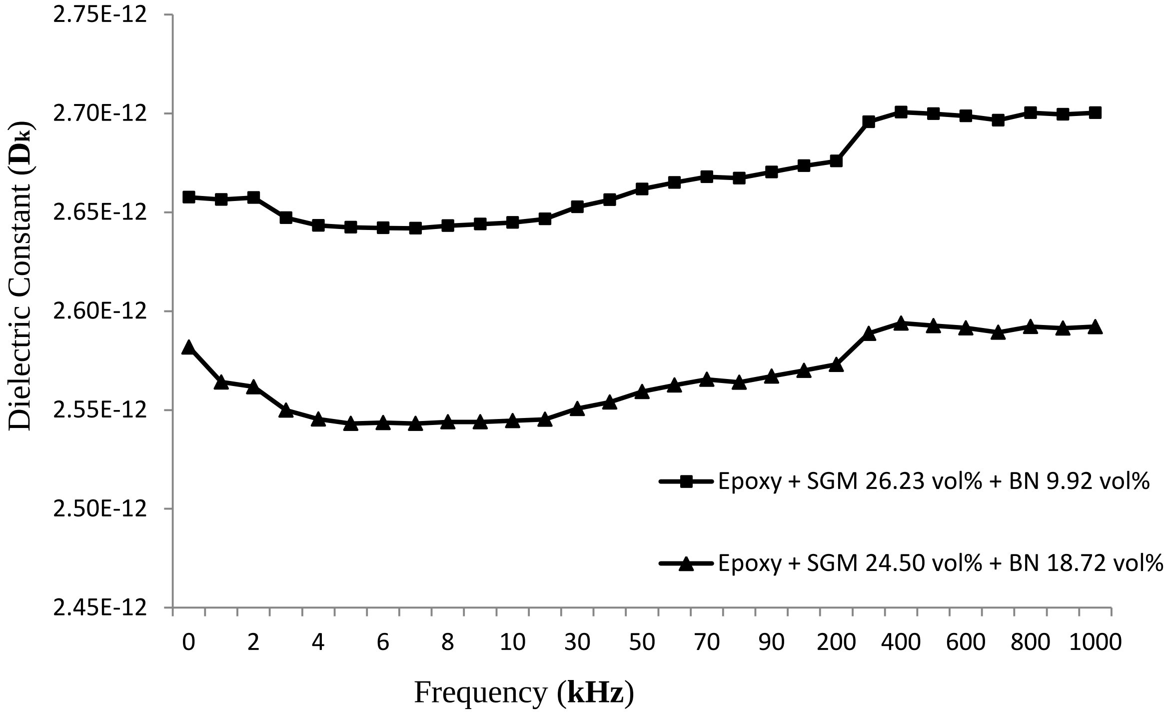

Fig 4.12: Variation of Dielectric constant as a function of Frequency for SGM-BN filled epoxy composite

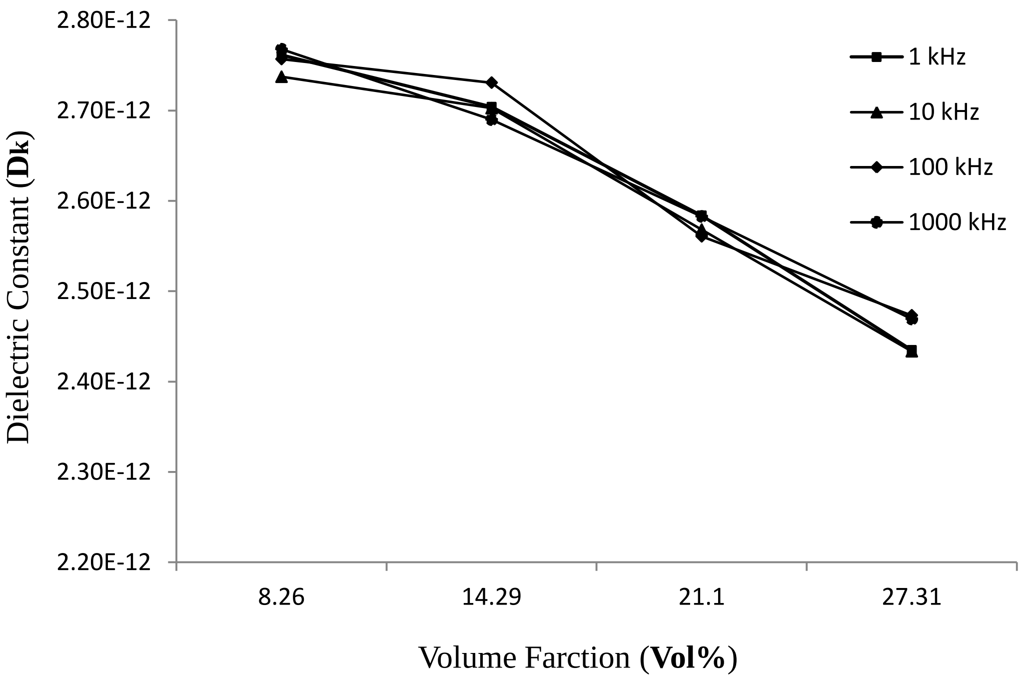

Fig 4.13: Variation of Dielectric Constant (**D_k**) as a function of Volume Fraction of SGM

MICROSTRUCTURE OF COMPOSITES

Fig: **4.14** and Fig: **4.15**; shows the microstructure surface of the composites containing different fillers. For Spherical Glass Microsphere – Epoxy composite, it is found that the SGM distribution is homogenous. For SGM-BN filled composites the orientation of the BN platelets in the composites is fairly random and the composite morphology is thus isotropic.

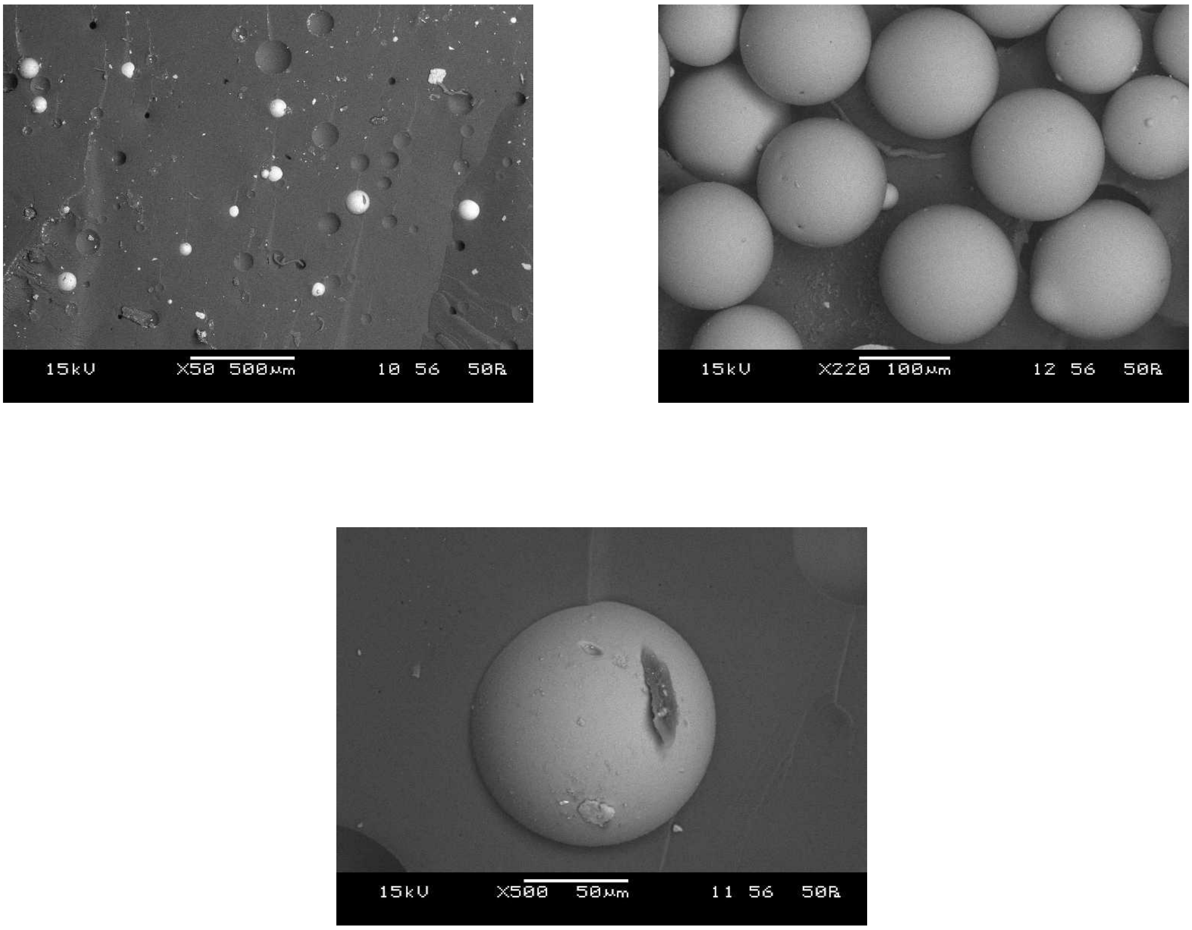

Fig 4.14: SEM micrographs of SGM-Epoxy composites

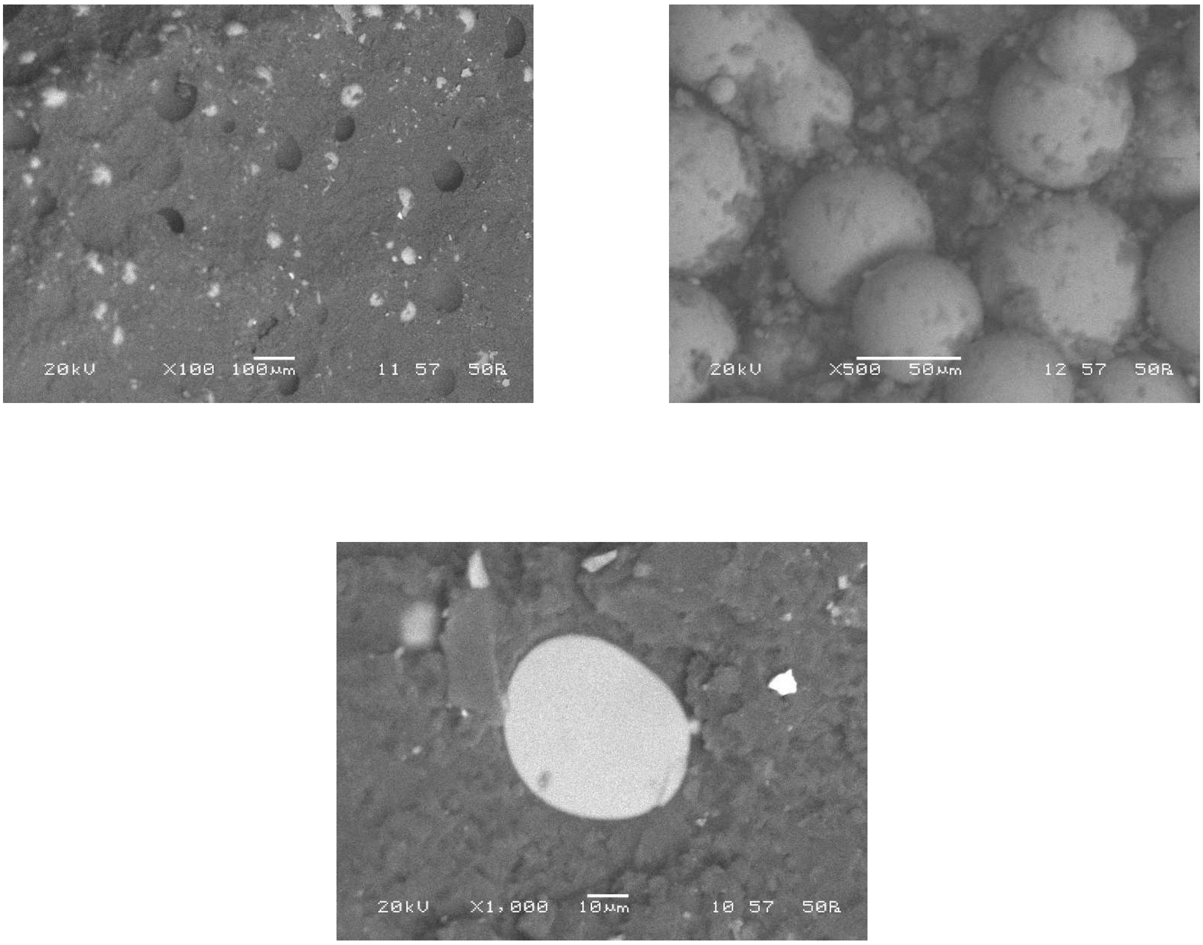

Fig 4.15: SEM micrograph of SGM-BN filled Epoxy composites

For the hybrid BN- filled composites, it is observed that the BN particles occupy the space between the SGM, resulting in high packing density of fillers in matrix, and thus heat conductive networks are easily formed in epoxy matrix. Additionally, it can also be observed that some BN particles are coated by epoxy, indicating a strong interfacial adhesion between filler and epoxy. The good adhesion of filler and epoxy is one of the significant contributions to modify the properties of the composite.

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Chapter 5
Conclusions

Chapter 5

CONCLUSIONS

- Successful fabrication of SGM filled epoxy composites is accomplished by hand-lay-up technique.
- Finite Element Method (FEM) can be gainfully employed to determine the effective thermal conductivity (**k_{eff}**) of these composites for different volume fractions of SGM.
- The values of thermal conductivity (**k_{eff}**) obtained for various composite models from FEM are in reasonable agreement with the experimental values for a wide range of filler content from 8.26 vol% to 27.31 vol%.
- The thermal conductivity values obtained from FEM are found to be more accurate with respect to the experimental values than the calculated values from existing theoretical models, such as Rule of Mixture, Maxwell's equation, Lewis and Nielson's model and Ratcliffe's model.
- Incorporation of 100 μm size SGM results in significant decrease in thermal conductivity for epoxy resin. Inclusion of **8.26** vol%, **14.29** vol%, **21.10** vol%, **27.31** vol% of SGM, the thermal conductivity of epoxy decreases by **22.03**%, **28.09**%, **35.53**%, **42.97**% respectively. Similarly, in comparison of neat epoxy resin with **20** vol% SGM + **5** vol% BN and **20** vol% SGM + **10** vol% BN of the thermal conductivity increases by **29.727** and **56.322** times.
- For SGM-Epoxy composite the dielectric constant (**D_k**) value decreases with increase in frequency with decrease in thermal conductivity and for SGM+BN-Epoxy composite with the decrease in (**D_k**) value there is also a simultaneous improvement in thermal conductivity of **11.154** for 20 vol% SGM + 5 vol% and for 20 vol% SGM + 10 vol% it is as high as **20.808**.
- With increase in thermal conductivity and simultaneously a lower value of dielectric constant (**D_k**), this new class of composites can be used for applications like electronic packaging material, encapsulations, thermal interface, electrical insulation as well as substrate materials.

Scope of future work

There is a wide ambit of investigation for the exploration of many other aspects like the thermal behaviour of particulate filled composites. Some recommendations are:

- Effect of filler size and shape on thermal properties of composites
- Exploration of new type of fillers for development of materials having high thermal conductivity and low dielectric constant.

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A STUDY ON THE DIELECTRIC PROPERTIES OF SGM-FILLED EPOXY COMPOSITES

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ABSTRACT

Materials used for electronic packaging and printed circuit boards need to have multi- functional properties such as adequate thermal conductivity and controlled dielectric const. Hardened neat epoxy inspite of its good mechanical strength, often cannot satisfy this demand. In view of this, in the present work, Solid glass micro-sphere (SGM) filled Epoxy composites, with filler content ranging from 0 to 20 vol% have been prepared with an objective to modify the dielectric properties of the epoxy. Dielectric constant measurements are made for these composites using a HIOKI- 3532-50 Hi Tester Elsier Analyser with an applied Ac voltage of 500mv in the frequency range of 1kHz to 1 MHz. However in this study it is also noticed that that the thermal conductivity of the composites decreased with increase in SGM content which is not desirable. Thus, inorder to obtain relatively high thermal conductivity and low dielectric constant simultaneously, this paper suggests further addition of some thermally conducting fillers like AlN or BN.

Keywords: Polymer composite, Spherical glass micro-spheres, Dielectric Constant

1. INTRODUCTION

With the rapid development of the electronic information industry, better properties are required for substrate and packaging materials, such as high thermal conductivity, low coefficients of thermal expansion (CTE), low dielectric constant, and thermal stability. Polymers, such as polyethylene, epoxy and polyamide are ordinarily used as these materials due to their high resistivity, low dielectric constant and excellent processability. However, these polymers suffer from disadvantages such as low thermal conductivity, high CTE ,low stiffness and strength. To offset these deficiencies, adding inorganic particles to a polymer is a versatile method. This method synergistically integrates the advantages of polymers and inorganic fillers; thus, the thermal, electrical and mechanical properties of the composites can be improved by properly selecting the filler components, shapes, sizes and concentrations [1].The dielectric properties including the dielectric constant (D_k) play an important role in the proper functioning of the electronic circuit board substrates. As the working frequency of electronic appliances increases, signal intensity losses become more sensitive. Therefore, small D_k is demanded for substrates in high frequency appliances to increase the velocity of signal propagation. Yung et al. [1] studied the AlN content dependence of thermal, electrical, and mechanical properties of epoxy–AlN composites.

Yung et al. [2] reported on the combination of high-thermal-conductive filler aluminum nitride (AlN) and boron nitide (BN) with low-dielectric filler (hollow glass microsphere, HGM) filled into epoxy matrix. They developed a new kind of polymer-matrix composite with both high-thermal conductivity and good dielectric properties by varying the size, shape, volume fraction, and composition of fillers. This study is of great importance for new packaging technologies of further increasing of working frequency and miniaturization of electronic devices. Suzhu et al. [3] investigated polystyrene composites filled with aluminum nitride. A special dispersion state of filler is achieved in these composites in which the polystyrene particles are surrounded by aluminum nitride particles. The results show that it is possible to improve thermal conductivity of the polymer at low filler contents with this kind of dispersion, so that the adverse effect of the filler on the dielectric properties of the composites may be minimized [4]. Shu-Hui et al.[5] found that, with the inclusion of aluminum nitride powder into the polyamide matrix, the thermal stability and the thermal conductivity of the composite were enhanced, while the dielectric constant increased slightly and the electrical properties altered to less degree . Zhu et al. [6] developed epoxy filled with AlN or BN composites with sufficiently high thermal conductivity and suitably controlled D_k value for PCBs application and investigated the effects of content , size, size distribution and morphology of two fillers on the thermal/dielectric properties of the composites.

Solid Glass beads (SGMs) consist of stiff glass which results in some unique properties, such as light weight, high strength low thermal conductivity and low dielectric constant(Dk). Based on these properties, SGMs have been used in the fabrication of polymer composite materials for different applications [7-10].These have multifunctional properties including high specific compressive strength, low moisture absorption and higher thermal stability which makes it more suitable for aeronautical and marine applications [10-13]. However, it is an astonishing fact that no paper has been published on the study of thermal characteristics, glass transition temperature (T_g) and electrical properties of SGM-Epoxy composites[14-18].One of the important applications of SGM is to reduce the D_k and dissipation factor(D_f) of the polymers that are used as circuit substrates and packaging materials, which is very important inorder to increase the velocity of signal attenuation, especially as the working frequency of electronic appliances increases.[13-16].The D_k of pure epoxy is relatively large and hence in this study epoxy matrix was filled with SGMs inorder to obtain composites with low D_k and D_f since SGMs possess low D_k and D_f.

2.0 METHODOLOGY

The composite samples with different SGM content ranging from 0 to 30 vol% are made by conventional hand-lay-up technique. Dielectric constant (D_k) measurements are taken on a Hioki 3532-50 Hi Tester LCR analyzer with an applied AC voltage of 500 mV; the frequency range was 1 KHz–1MHz. The used samples are disc-shaped, and both sides of the samples are coated with thin aluminium foil. The dielectric constant (D_k) is the relative permittivity of a material which is calculated from capacitance by $D_k = Ct/\epsilon_0 A$, where t was the thickness of the discs, ϵ_0 the vacuum dielectric constant that is 8.85x 10^{-12} farad per m, and A the disc area.

3.0 RESULT AND DISCUSSION

Figures 1 shows the curves indicating the variation of the dielectric constant with the frequency for the Epoxy composites with different SGM content. The dielectric behavior involves different polarizations and the polarization rate is dependent on temperature and frequency. At low frequencies, the polarization will have more time to complete compared with that at high frequencies. Thus the degree of polarization of material is high and the dissipation of polarization is low at low frequencies i.e. the D_k decreases but the D_f increases with increasing frequency. As shown in all these figures, the D_k decreases with the increase in frequency for all the samples irrespective of the material composition.

Figure .2 presents the variation of the composite D_k as a function of the SGM content at different frequencies (1 kHz- 1 MHz). It is found that the D_k value increases with increasing SGM content invariably for all the samples. It is found that up to 5 vol% of SGM in the composites, the D_k value decreases with increasing SGM content invariably for all the samples. But beyond that, it suddenly shows an increasing trend and when the SGM content is increased from 5% vol% to 10 vol%, the value of the dielectric constant is found to reduce from 2.765 to 2.700 (for 1 kHz) and 2.74 to 2.70 (for 1 MHz). It may be mentioned here that the D_k for cured epoxy is 3.89 in the range of 1kHz-1MHz.

SGM content (vol%)	SGM content (wt%)	Thermal conductivity (W/mK)
0	0	0.363
5	6.69	0.316
10	13.15	0.301
15	19.39	0.269
20	25.42	0.246

Table 1 Thermal conductivity measurement of the composites with different filler content

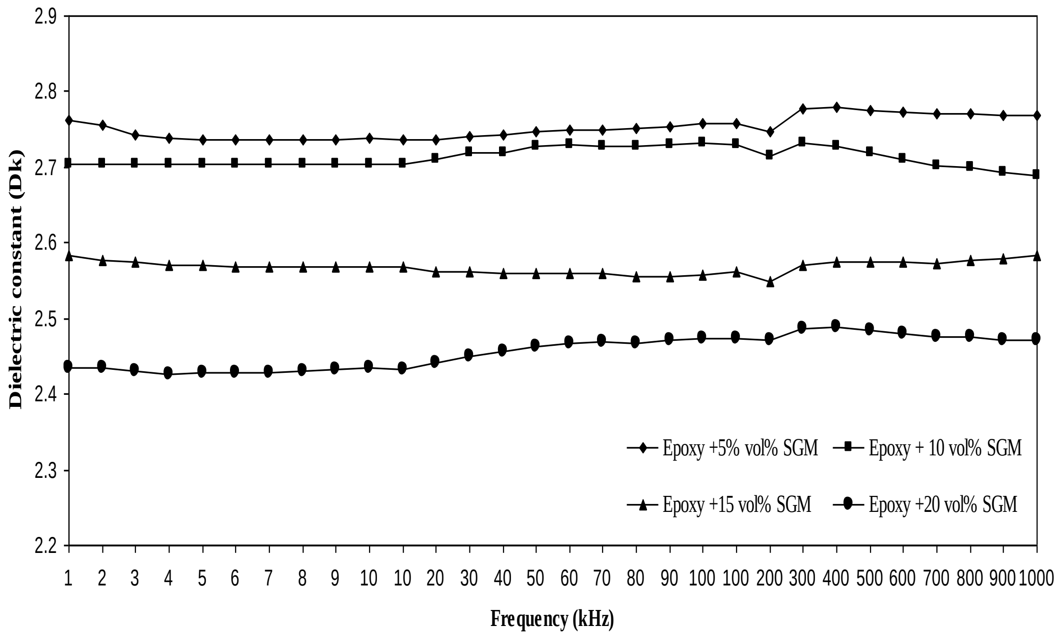

Fig.1.Dielectric constant as a function of frequency

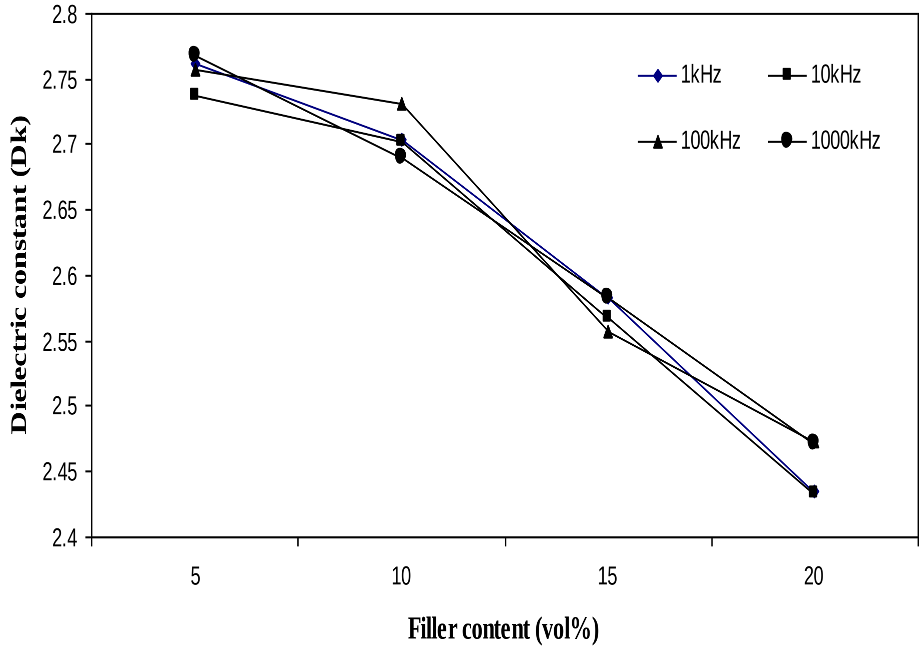

Fig. **2** Variation of dielectric constant with SGM content at different frequencies

The thermal conductivities of composites with different SGM content obtained from experiment are shown in Table.1. The thermal conductivity decreases with increase in SGM content. The thermal conductivity of neat epoxy is 0.363W/mK. Unitherm™ Model 2022 is used to measure thermal conductivity of different samples. The tests are in accordance with ASTM E-1530 standard.

4.0 CONCLUSION

An investigation about the effect of SGM content on the dielectric performance of epoxy-matrix composites is done. Compared to neat epoxy the D_k and thermal conductivity of Epoxy + 10 vol% SGM decreased by 20.15% and 32.23% respectively. In order to increase the thermal conductivity and simultaneously keep a low dielectric constant, thermally conductive fillers like AlN or BN with suitable volume fraction should be added onto these glass micro-sphere filled epoxy composites. It is expected that with tailor made thermal conduction and electrical insulation this composites have scope of utilization in electronic packaging, printed circuit board substrates etc.

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